AIR COMMAND AND STAFF COLLEGE

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FINDING THE ENEMY: USING 3-D LASER RADAR (LADAR) IMAGING FOR REAL
TIME COMBAT IDENTIFICATION OF GROUND TARGETS IN AN OBSCURED
ENVIRONMENT

By

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Abstract

Laser Radar (LADAR) offers advantages over traditional surveillance technologies such as Synthetic Aperture Radar (SAR) and Electro-Optical/Infrared (EO/IR) sensors. LADAR provides very high resolution, can produce 3-D images, is all-weather capable, and can detect obscured ground targets. These advantages make LADAR an attractive alternative to SAR and EO/IR. The high resolution and ability to produce 3-D images that LADAR provides also have the potential of supporting real-time target identification using Automatic Target Recognition (ATR) algorithms to match LADAR images with preloaded templates of potential targets. This paper addresses the broad problem of identifying ground targets in real-time to enable capture or targeting.   Specifically, this paper focuses on the following research question: How can LADAR be used to identify ground targets real-time in an obscured environment? The research shows that providing real-time target identification with LADAR by 2035 is feasible. The paper also identifies technologies required and when they must be available to support this future state.

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1.   Introduction

Intelligence, Surveillance, and Reconnaissance (ISR) information has become increasingly important in supporting warfighters in the battlespace. With the transition from conventional wars to the unconventional counter-insurgency operations the United States is involved in today, it is increasingly difficult to target the enemy. Often, the enemy is intermixed among the civilian population, appearing for only a short time to conduct operations and then blending back into the populace. The United States has greatly increased the number of ISR platforms to help with this problem, adding both manned and unmanned platforms to collect ISR information. Most of this data, however, is collected on the platform and analyzed post-mission. Analyzing ISR data post-mission is useful to develop trends and help plan future ISR collection activities, but by the time the data is analyzed and the target is identified, it is long gone. In addition, urban environments and heavy foliage or camouflage make target identification extremely difficult. Ground targets are often hidden by natural and man-made objects, or are lost in the clutter of very busy scenes.

Much work has been done on improving ground target detection in obscured environments. Technological advances have allowed sensors to become more accurate and algorithms have been implemented to reduce clutter. Technological advances have also been made in the area of Automatic Target Recognition (ATR) software and algorithms to alleviate the dependence on the human in the loop for target identification. These advances, however, have only been demonstrated thus far and have not been fielded, and many challenges still exist in getting to a real-time target identification capability.

One of the biggest problems with current ATR technologies is that identification of targets is not accurate enough even in a benign environment. In cluttered and obscured

environments typical of operations, ATR results are even more inaccurate. Much work is being done to improve algorithms and techniques to address ATR accuracy. Another way to increase ATR accuracy is to improve the images fed into ATR algorithms. Laser Radar (LADAR) is an emerging technology that could provide higher resolution images. This, coupled with improvement in ATR algorithms, could allow for real-time identification of targets.

This paper addresses the broad problem of identifying ground targets in real-time to enable capture or targeting.   Specifically, this paper focuses on the following research question: How can LADAR be used to identify ground targets real-time in an obscured environment? LADAR offers advantages over traditional surveillance technologies such as Synthetic Aperture Radar (SAR) and Electro-Optical/Infrared (EO/IR) sensors. LADAR provides very high resolution, can produce 3-D images, is all-weather capable, and can detect obscured targets. These advantages make LADAR an attractive alternative to traditional SAR and EO/IR. The high resolution and ability to produce 3-D images that LADAR provides have the potential of supporting real-time target identification using ATR algorithms to match LADAR images with preloaded templates of potential targets.

In line with the central question, the research helps determine the feasibility of providing real-time ground target identification with LADAR by 2035 and identifies technologies that are required and when these technologies must be available to support this future state.

2.   **Background**

2.a. Surveillance and identification of targets

Surveillance is a broad term that simply means the observation of a situation, activity, or group. There are many methods of collecting surveillance information, such as imagery, signals, humans, and computers. This paper addresses imagery surveillance, or Imagery Intelligence

(IMINT), and specifically ground imagery collection by air. As far back as the late 1700s, hot air balloons were used to observe enemy formations on the ground. With the advent of the airplane in the early 1900s, surveillance by air continued with human observation as well as film photography and, later, digital photography. Other sensors were developed to overcome the visual method requirement that imagery be collected during daylight and clear conditions that visual methods required. These sensors include IR and SAR. LADAR is a newer type of surveillance that provides higher resolution images than IR and SAR and also provides images in 3-D instead of 2-D.

For the purposes of this paper, target identification is defined as identifying the class and type of the target; for example, being able to tell if a vehicle is a tank or a truck. Being able to distinguish the type of target means being able to tell if the tank is a Russian T-72 or a U.S. M1A1. For the purposes of this paper, target identification does not mean being able to tell if the tank is the exact same tank imaged earlier. The purpose of this paper is to address ground target identification for real-time targeting in the battlefield. Being able to tell what type of target is sufficient in most targeting cases.

2.b. Current imaging techniques

SAR and EO/IR are the surveillance methods used most frequently today. These traditional methods do not provide the resolution required for real-time target identification and have limited use in an obscured environment. SAR provides an all-weather and day/night capability, but its resolution limits its usefulness for target identification. "The traditional approach to imaging objects hidden by foliage relies on long-wavelength synthetic aperture radar (SAR) to penetrate through the vegetation with minimal attenuation. . . . Because the wavelength is typically several metres, however, the resolution is limited, and the false-alarm rate for target

detection is high."[1] SAR utility is also limited because only stationary targets can be imaged.

EO/IR sensors are also currently used for surveillance. EO/IR imaging ". . . tends to have much

finer spatial resolution than radar and therefore is capable of subpixel target detection, but is

limited by weather, daytime imaging conditions (except in the case of short wave infrared, which

can image at night), and often can only image at or near nadir viewing geometry."[2] In addition,

EO/IR sensors cannot penetrate obscurations such as foliage.

2.c. Evolution of LADAR

The birth of the laser dates back to the late 1950s. The process of laser development took

place during ". . . the period between September 1957, when Charles H. Townes of Columbia

University first wrote into his notebook his preliminary ideas for 'a maser at optical frequencies,'

and December 1960, when Ali Javan, William Bennett and Donald Herriott of Bell Telephone

Laboratories operated the first continuous laser."[3] The idea of the laser grew out of the

Microwave Amplification by Stimulation Emission of Radiation (MASER) developed by

Charles Townes in 1954.[4] "A LASER is a MASER that works with higher frequency photons in

the ultraviolet or visible light spectrum . . ."[5] The Air Force Office of Scientific Research was

involved as a sponsor of laser technologies from the beginning. Once the laser was developed,

the military actively funded and pursued uses for laser technology such as communications, anti-

missile defense, and imaging.

LADAR is a promising imaging technique.   "LADAR images are created by scanning a

scene with a pulsed laser. The return time and beam strength are recorded. The return strength

produces intensity data and the time of return leads to range data."[6] This intensity and range data

is used to produce 3-D images of the scene.

3. 3-D LADAR Imaging

3.a. Basic Designs

"Laser radars constitute a direct extension of conventional radar techniques to very short wavelengths."[7] LADARs have advantages and disadvantages in imaging when compared to conventional radars due to their operation at these shorter wavelengths. ". . . [L]aser radars are capable of higher accuracy and more precise resolution than microwave radars. On the other hand, laser systems are . . . generally restricted to shorter ranges in the lower atmosphere than microwave radar."[8] Though LADAR must normally be operated at shorter ranges than conventional radar, the fact that LADAR provides more accurate, higher resolution images, as well as 3-D images, makes real-time target identification more likely because 3-D images are more easily matched to the 3-D ATR templates.
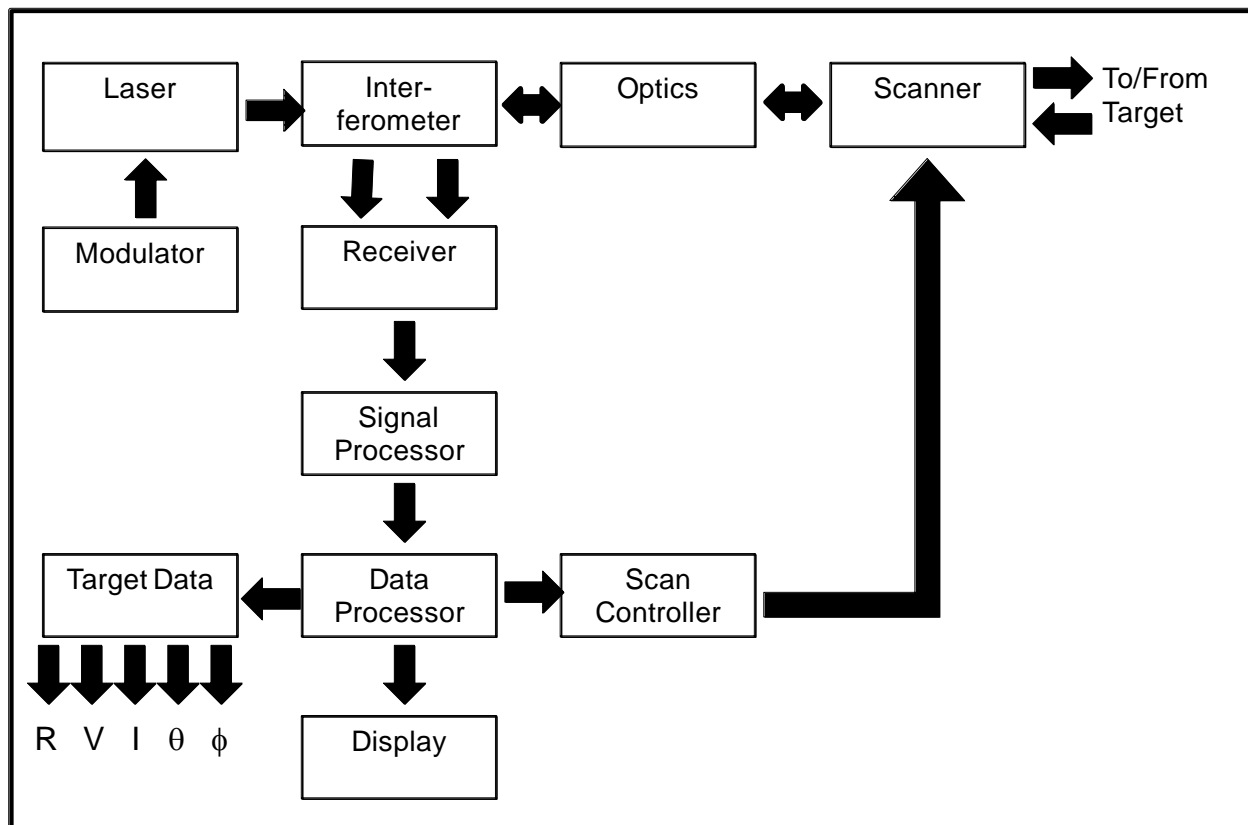
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│  │Target Data│◀─│   Data   │─▶│   Scan   │                         │
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Figure 1 Ladar Block Diagram[9]

A typical LADAR block diagram is shown in figure 1 above. "In this configuration the laser is modulated to provide information to the transmitted signal, which is coupled through the interferometer, optics, and scanner to illuminate the scan field of interest. The received signal is then coupled, via reciprocity through the interferometer, to the receiver detector, where it is mixed with a sample of the laser signal in the form of a local oscillator."[10] The LADAR image, along with target position, range, and velocity, is compiled by the data processor once the receiver output is processed by the signal processor.[11]

Several parameters should be taken into account in the design of a LADAR system. The first of these is Signal to Noise Ratio (SNR). SNR is related to signal current versus noise current terms: ". . . the summation of noise terms involves shot noise, thermal noise, background noise, dark current, and . . . local oscillator noise."[12] Increasing the SNR increases the transmitted power.

The second parameter is desired beam width.   The beam width is affected by wavelength. ". . . [F]or a fixed aperture size, as the wavelength decreases, the beamwidth decreases. For a 1-cm waveband and a 30-cm aperture, the beamwidth is approximately 33 mrad. Similarly, if the wavelength is decreased to 10 μm, the beamwidth becomes 33 μrad for the same aperture size."[13] Since LADARs operate at shorter wavelengths than conventional radar, the aperture size limits the beam width as compared to conventional radar.

The third parameter is the search field. The smaller beam width of LADAR affects the ability to cover large search fields (areas). ". . . [L]aser radars require high repetition rates or long acquisition times in order to perform the target search function, unless multiple beams are used."[14] Since longer acquisition times affect the ability to do real-time target identification,

higher data rates are necessary. These higher data rate transmissions affect the data rates required of the receiver, signal processors, and data processors.

3.b. LADAR Implications

Despite the smaller beam width and shorter range of LADAR as compared to other surveillance methods, using LADAR for target identification offers many advantages. One of these is simultaneous collection of various types of data. ". . . [T]he ladar has the ability to acquire both reflectance and geometric data simultaneously from the target, thus providing potentially a more powerful classification tool than a purely passive source in the visible or infrared bands."[15] LADAR data can also be collected at more than one wavelength to help determine the type of target. "If a multi-spectral capability is included, that is, the ability to acquire images of the target at several different wavelengths, then it is possible to combine the 3D geometry of the laser ranging with the spectral signature of the response to provide very informative data about the nature of the target."[16]

LADAR also enables detection of targets in clutter or that are obscured. One of the keys to doing this is the ability to distinguish between man-made and natural surfaces. "A method for improving the determination of which pixels are on target is to use the polarization components of the reflected light. Laser light retroreflected from man-made (smoother) surfaces is depolarized less than light from natural (rougher) surfaces."[17] By using the polarization components of laser light, the target can be separated from objects around it so that the target's 3-D shape is better estimated. This method increases the ability to identify the target using target recognition algorithms. The ability to declutter the target from its environment makes LADAR useful in detecting targets that are camouflaged, as well as those obscured by foliage or those with high background clutter such as are found in an urban environment.

The high resolution of LADAR sensors also allows high accuracy 3-D imaging to identify small targets. This technology will allow not only identification of vehicles, but could also enable identification of personnel through facial recognition. "An example of such high accuracy 3-D imaging was recently demonstrated for face recognition and person identification at ranges up to 500 m."[18] The potential to identify personnel in real-time would revolutionize the power of ISR.

Finally, as discussed previously, data rates are critical to obtaining images in a reasonable amount of time. 3-D flash LADAR is one technique being developed to increase data rates. 3-D flash LADAR, which takes an entire frame of 3-D LADAR data with one laser pulse, provides higher data rates than conventional point scanner systems.[19]

4. Real-time Identification

4.a. Methods for real-time identification using LADAR images

LADAR's high resolution and ability to produce 3-D images means it provides the potential of supporting real-time target identification. Three methods exist to identify a target once an image of that target is available. First, the image can be analyzed by a person who can identify the target. This human in the loop method is the one most used today. It is accurate but also time-consuming and limited by available personnel resources. More critically, this method makes real-time identification of targets nearly impossible. The second method involves the use of computer algorithms. By comparing images with pre-loaded templates, computer algorithms are able to identify targets that match target templates available in its database. This technology, called ATR, has been demonstrated but has not yet been employed operationally. The third method combines these two methods by using ATR to identify targets and then passing this information to a human in the loop to confirm the identification. This combination method can

also be used in reverse, with the human in the loop indentifying the target based on an image and then feeding that image into the ATR algorithm to confirm correct identification.

4.b. ATR Techniques

ATR has been demonstrated using a number of different sensors. One of the problems with the ATR systems already demonstrated is that false alarm rates have been too high to make these systems operationally useful. One of the reasons for these high rates is that the images are not taken at the same aspect and conditions as the template data used in the ATR algorithm. 3-D images provided by LADAR can help improve ATR performance by enabling easier matching of an object's geometric features in an image to a template. "The main advantage of 3D images lies in the measurement of the third dimension: the range (or height). Consequently, the geometrical features of an object are easily derived from the 3D image. These features are invariant to rotation and scaling, and insensitive to temperature and sun illumination. As a result, target recognition becomes feasible, achieving high probability of recognition along with very low False Alarm Rate (FAR)."[20] A number of techniques are being studied to improve ATR performance with LADAR. These include component-based matching, use of fuzzy algorithms, probabilistic model matching, and the use of neural networks.

Component-based matching is especially important in the obscured environments this paper addresses because the entire target is not visible. Component-based matching is inspired by human vision. "For example, you are asked to find and circle all cars in a street picture. You do not have any detailed information such as models or colors. You may 'scan' the picture several times with abstract patterns. . . . Most likely abstract patterns of less details (consisting of key components) are tried first for fast processing purpose[s]. . . . In addition, the target can be recognized even if partial patterns (only cabin or half car) are visible."[21] Instead of having

just full-image templates in the ATR algorithm with which to match the LADAR image, the ATR algorithm would contain components of the image template that could be matched with the image, as well as the full-image templates. The component templates could be either used as an initial matching technique, followed by full-image templates for fine-tuning the matches, or component and full-image templates could be used together to best match the LADAR image.

The second technique to improve ATR performance with LADAR is the use of fuzzy algorithms. "Typically an automatic target recognition (ATR) system comprises a sequence of crisp image processing and pattern recognition operations, each of which produces a binary decision (or value). . . Propogation of (incorrect) crisp decisions based on thresholds can lead to high confidence values at the system output for false positives and false negatives."[22] Instead of using these crisp binary decisions along the decision process, fuzzy algorithms provide a weighted value along the design process and a binary decision is postponed until the end of the process.[23] This method potentially increases the accuracy of target identification while reducing FARs.

The third technique to improve ATR performance with LADAR is probabilistic model matching. This method is similar to fuzzy algorithms and is based on the Bayesian Decision Theory, ". . . in which probabilities are associated with individual events or statements rather than with sequences of events."[24] Using this theory, information is gathered about an item, the knowledge gained is assessed, and, based on this assessment, new data on the item is gathered to address remaining uncertainties. Then, both old and new data are incorporated to refine understanding of the item. For target identification, for example, initial information gathered might lead to the decision that a target is a vehicle. This knowledge is used and new data are gathered to determine what type of vehicle the target is. There is no need to gather additional

data on whether the target is an aircraft, vehicle, or person, because it has already been determined with a certain threshold probability to be a vehicle. Once the target is determined to be a vehicle, it is only compared with ATR templates of vehicles instead of to the entire template database. Probabilistic matching has been shown to increase target identification rates.

The fourth technique for improving ATR performance with LADAR is the use of neural networks. Neural networks increase the probability of target identification because they are able to "learn" to recognize patterns based on past applications. In this way, they are better able to handle imprecise or complicated data. Work is currently being done to determine which features of targets should be used to train the neural networks. "In target identification, one of the difficult tasks has been the extraction of features to be used to train the neural network which is subsequently used for the target's identification. . . . The performance of an identification system may be erroneous if the extracted features are subjected to change by factors that were not considered during the training process."[25] If a valid method for training neural networks can be determined, their use will increase the probability of target identification.

5. Futures Research Methodology

Environmental scanning, relevance tree, and backcasting were used in the research of this paper. A description of these research methodologies is found in appendix A.

5.a. Environmental Scanning

The research reveals that using LADAR for real-time target identification is a promising technology that has a good chance of being available for operational use by 2035. The basic technology has been demonstrated. Advances in laser resolution and coverage, image processing, sensor pointing accuracy, and target identification algorithms are necessary to make real-time target identification viable. The research also reveals other uses for LADAR images

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such as target change detection, detection of roadside IEDs, battle damage assessment, and detecting and identifying chemical and biological agents along with potential domestic security applications. While these other uses are outside the scope of this paper, they make pursuing this technology even more attractive.

5.b. Relevance Tree (shown in appendix B)

5.b.1. LADAR

The development of LADAR by the year 2035 relies on technological advances, resolution of safety concerns, and development of a support infrastructure. Technological advances include advances in the LADAR receiver sensitivity, scanner and optics speeds, signal and data processing speeds, and sensor pointing accuracy and stability. Safety concerns include eye safety, long-term effects of laser exposure, and environmental effects. Development of a support infrastructure for LADAR must address maintenance, training, frequency management, and logistics.

LADAR has already been demonstrated in a number of different applications; however, the technology has been too immature for operational use. "The lasers were too large and heavy and required high power. The detectors lacked the bandwidth and large array formats for reasonable fields of view. Computers were too slow to enable onboard processing."[26] Advances are being made to improve LADAR technology, and future advances will be necessary to make LADAR viable for real-time target identification.

Receiver sensitivity affects the performance of the LADAR system. In order to resolve obscured targets, such as those under camouflage, very small pulse widths and very large bandwidths are required. "Separating a target from overlaid camouflage requires pulse widths of less than 2 ns and bandwidths of greater than 500 MHz. . . . Resolving such closely spaced

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returns requires a high-bandwidth detector and readout electronics."[27] Current LADAR systems used for terrain-mapping today typically use pulses on the order of 10 ns. Scanner and optics speed are also important, since they affect the resolution and range achieved. Signal and data processing speeds are important as well. Finally, pointing accuracy and stability of the laser greatly affects operational utility. Pointing accuracy must be able to place the beam on a chosen object and follow moving objects. Pointing stability must be such that the beam can remain on an object while the aircraft is moving in turbulence and wind.

One of the primary concerns in LADAR use is eye safety. Many lasers can temporarily or permanently affect vision. Lasers that operate at 1550 nm are eye safe, but their power output is not as high as those in the 600-800 nm range, and they are also less common. The laser repetition rate and pulse length are also important parameters that affect the performance of the laser for imaging, further adding technological challenges to achieving eye safety as well as desired performance.

LADAR's long-term effects on humans and equipment must also be studied before it can be approved for widespread operational use, since this application will result in frequent lasing of people. Environmental effects of widespread LADAR use should also be studied and results made available to the international community. Any adverse effects must be mitigated.

Finally, maintenance, training, frequency management, and logistics should be considered. In the area of maintenance, LADAR must have an acceptable Mean Time Between Critical Failure (MTBF), be able to be repaired in an acceptable amount of time, and have Built-In Tests (BIT) so maintainers can diagnose problems in a reasonable amount of time. The type of maintenance (2-level or 3-level) should also be considered, along with system accessibility for

maintenance functions and the type and frequency of required routine maintenance. Acceptable requirements for these parameters must be set based on inputs from the maintenance community.

Training is an integral part of transitioning this technology to the operational environment. Training manuals and sessions for operators and maintainers must be extensive enough to ensure proper operation of the equipment, but they must not be so technical that the average military operator cannot operate and/or maintain the system. Training on the use of any associated equipment to maintain or operate the system must also be addressed.

The system must be able to be operated on a regular basis within the United States for training and worldwide for operations. Interference with other systems should be addressed and any effects mitigated. Frequency approvals for use during testing, training, and operations must be obtained.

Finally, logistics should be addressed from the beginning of development to ensure that the LADAR system can be operated efficiently throughout its life cycle. Support equipment, storage, distribution, disposal, and personnel requirements should all be considered. All support equipment necessary for the maintenance and operation of the system should be specified. Support equipment availability should also be addressed to ensure all equipment is available when needed. Storage, distribution, and disposal methods should be specified and proper facilities should be made available for each of these. Personnel requirements should also be specified, including number of personnel required for all maintenance and operations activities.

5.b.2. ATR

The development of ATR by the year 2035 relies on algorithms development, template development, and display requirements. Algorithms development includes addressing FAR concerns, probability of successfully matching targets to templates, and the types of algorithms

to be used. Template development includes the number and type required, accuracy required, process for loading, how updates are handled, and development of a centrally located and funded template generation capability. Display requirements include how the ATR information is presented to the operator.

Many types of algorithms have been demonstrated for ATR, but additional work is necessary to make these algorithms operationally useful. Systems demonstrated so far have had unacceptable FARs. Specific FAR values from the demonstrations are classified, but these values were deemed unacceptable according to military operators involved in the demonstrations. These rates must be improved so that operators are able to trust the ATR system. The specific FAR percentages required have not yet been developed and this issue is addressed in the CONOPS section (5.b.3).

Along with reducing FARs, additional work is necessary to increase the probability of successful matching of targets to templates. If a valid target is imaged, correctly matching it to the correct template for positive identification is critical. Just as falsely identifying targets creates additional work and degrades trust in the systems, so does not identifying valid targets that are imaged. Much work is being done today to improve current ATR algorithms and to develop newer, more accurate algorithms using neural networks and component- based recognition. This work must continue until algorithms have advanced enough to provide target identification with acceptable false alarm and detection rates.

Template development goes hand-in-hand with algorithms development. The algorithms used will help determine the required number, type, and accuracy of templates. Also, the process for loading and updating the templates must be developed and documented. Finally, a centrally located and funded template generation capability would prevent duplication of effort and ensure

all platforms have access to the most up-to-date templates. The development of a centralized template generation capability is important in operationalizing the ATR capability.

Finally, display requirements for ATR information should be developed and documented to support operationalizing ATR. Display requirements are dependent on the CONOPS for this capability, so the ATR community should work closely with operators as they develop the CONOPS to ensure that ATR displays provide the information required by operators based on the CONOPS.

5.b.3. CONOPS

The development of a CONOPS by the year 2035 relies on beam width, range, resolution, false alarm and detection rates, identification time, use with other sensors, assisted versus unassisted identification, display information, and imagery transfer. In order to develop requirements for all the parameters listed above, a CONOPS must be developed that specifies how this capability will be used. Additional requirements not listed here will also flow from the CONOPS. Often, technologies are developed in a laboratory environment without information on how they will be used. This has been the case with LADAR and ATR. In order to optimize these technologies, development of a CONOPS is necessary before proceeding past capability demonstrations to operational development. Both LADAR and ATR technologies have been successfully demonstrated for potential use in target identification. CONOPS development addressing the requirements listed above is essential so that optimization of these technologies can be addressed.

5.c. Backcasting

5.c.1. LADAR

The Jigsaw program executed by the Defense Advanced Research Projects Agency (DARPA) demonstrates the current state of development of LADAR for identification of targets in an obscured environment. This program demonstrated the capability to ". . . perform target identification day or night, through foliage or camouflage." The proof of concept was completed by DARPA in a laboratory environment using a LADAR testbed. "The sensor uses a short-pulse laser to illuminate the forest canopy above a potential target. While most of the laser energy is reflected or scattered by foliage, a small amount passes through the interstices in the canopy to reach the ground. The radar captures the time of flight of the returned pulses and encodes them as a function of range to form a 3-D image of the scene called a frame. . . The Jigsaw sensor will combine many frames of data from multiple aspects to create a composite, high-resolution 3-D image of the target beneath the foliage."[28] Modeling and simulation was also done, and a demonstration planned that would build prototypes to fly on a helicopter. Two contractors built prototypes for the demonstration, but no reports were found that show the demonstration was completed or what the results were. Still, the technology was successfully demonstrated in the lab, showing that LADAR is a promising technology for real-time target identification of obscured targets.

In order to reach the future state described in section 5.b.1., the technology focus should first be on improving receiver sensitivity and scanner and optics speeds. Improvements in pointing accuracy and stability should also be pursued to improve LADAR performance. Second, the feasibility of developing a multiple wavelength LADAR sensor should be investigated to improve sensor performance. Third, integration with other surveillance sensors such as SAR and

EO/IR should be investigated. One of the problems with LADAR is that the beam width is narrow compared to other sensors. This makes scanning for targets difficult and time consuming. Other sensors or intelligence information could be used to provide initial location information and then hand off that information to the LADAR sensor to provide identification through high-resolution 3-D imagery. Fourth, identification of moving targets with LADAR should be pursued. Finally, safety studies should be performed to determine any adverse effects from frequent lasing and mitigation of any effects should be pursued.

5.c.2. ATR

A number of recent demonstrations have proven the utility of ATR. One recent demonstration, Bold Quest in 2007, demonstrated ATR on a Joint Surveillance Target Attack Radar System (JSTARS) aircraft. During the demonstration, ATR algorithms were used with SAR images from the JSTARS radar to identify stationary ground targets. The demonstration successfully showed the feasibility of using ATR in an operational scenario.

To get to the future state for ATR as described in section 5.b.2., first and foremost, improvements in ATR algorithms are necessary. The current state of ATR algorithms produces FARs too high to be acceptable for operational use. In addition, these current ATR algorithms have only been demonstrated in benign (i.e., low clutter) environments, so FARs in more operationally representative environments would potentially be greater. A number of ATR algorithm techniques are discussed in section 4, such as component-based target recognition, fuzzy logic algorithms, and use of neural networks that should be pursued to improve ATR performance. These new techniques should be tested in more operationally representative environments so that more accurate performance data can be obtained. Second, ATR performance specifically with LADAR should be pursued. To date, ATR has been demonstrated

with other sensors, but no data could be found on ground or flight demonstrations of ATR with LADAR. Some studies and laboratory work have been done on ATR with LADAR, as well as modeling and simulation. Work on ATR with LADAR should expand to include technology demonstration in open air environments, both benign and operationally representative. Finally, more work on ATR templates should be pursued. Current ATR templates should be consolidated and centrally located. Additional work should be pursued to improve current templates and add templates for additional targets. To ensure that templates are sufficient for ATR use, standards should be developed that document the fidelity of templates required for use with LADAR sensors. Optimization of templates for specific sensors or specific environments may be necessary. Studies should be undertaken to determine whether this is necessary and, if so, how templates can be optimized to provide the best performance from ATR systems.

5.c.3. CONOPS

To date, little work has been done to develop a CONOPS specifically for LADAR sensors. However, CONOPS documents exist for current surveillance platforms and sensors. In addition, some CONOPS development has also been done for ATR during recent demonstration programs. To reach the future state for CONOPS as described in section 5.b.3, a CONOPS development team should be formed. This team can take the information in current surveillance and ATR CONOPS documents and use it to develop a CONOPS for real-time target identification using LADAR. The team should consist of operators and maintainers from the surveillance community. Technical experts that can provide information on LADAR and ATR should also be included on the team.

6. Operational Utility of LADAR

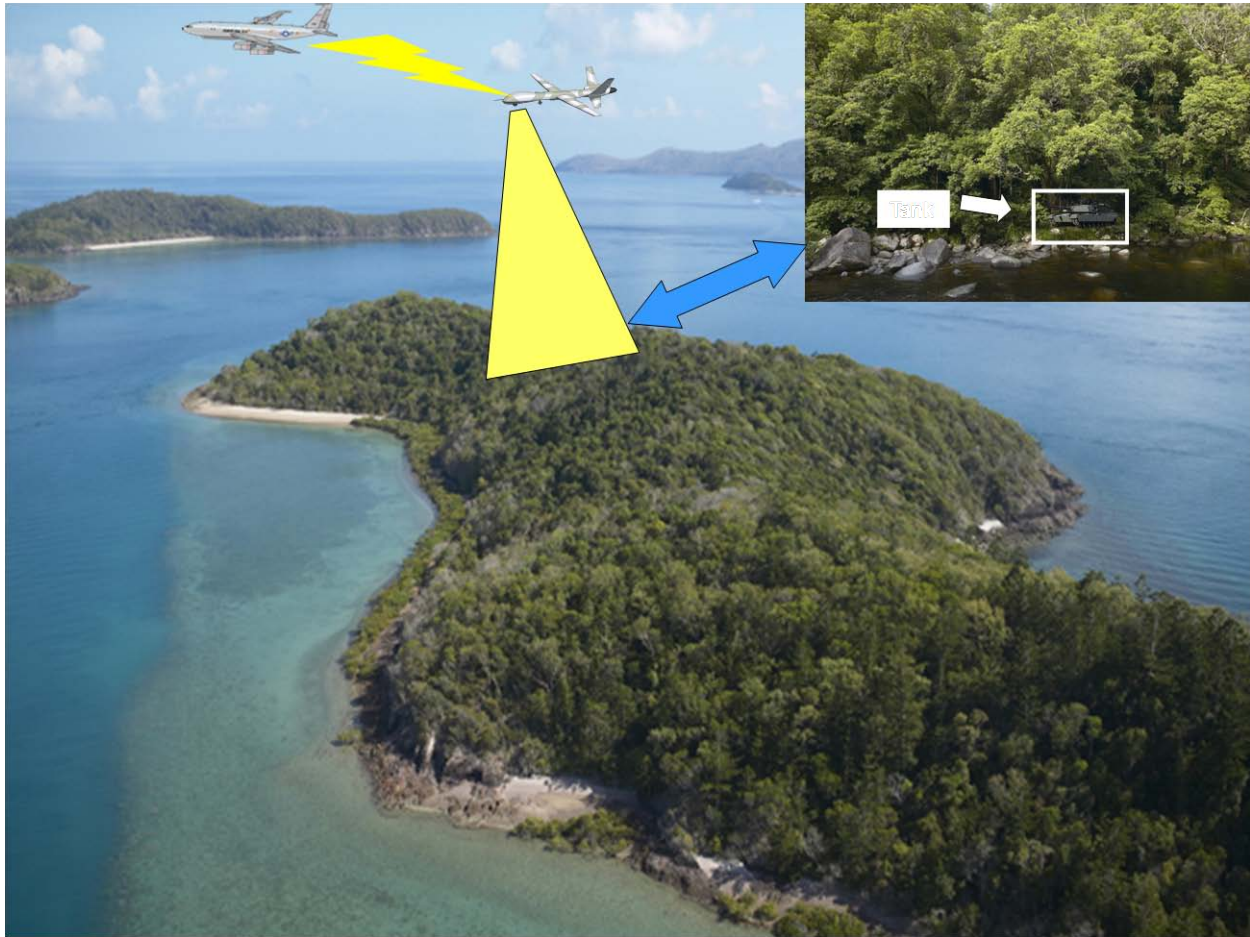### 6.a. Vignette 1: Target Identification Under Foliage

Figure 2 Vignette 1: Target Identification Under Foliage

The first vignette that demonstrates the operational utility of LADAR for real-time target identification in an obscured environment is that of targets obscured by foliage, as illustrated in figure 2 above. In it, a vehicle is hidden along a tree line. A JSTARS aircraft using SAR detects the vehicle, but it cannot be identified. The JSTARS cues the LADAR platform to the location of the vehicle via Link-16. The Link-16 target shows up on the LADAR operator's screen with a request to identify the vehicles. The LADAR operator cues the laser to the target location and begins collecting 3-D images of the target at different aspects as the LADAR platform performs a racetrack orbit. As the individual images are collected, the data processor forms a composite

image of the target. "By sensing the depolarization of the reflected light at every pixel, the pixels on target can be distinguished from pixels on clutter and background. With a less ambiguous determination of which pixels are on target, the target's 3-D shape can be more accurately estimated, leading to a more accurate identification of the target."[29] By using this depolarization method, a high-resolution 3-D image of the target is passed to the ATR algorithm and the operator's display. As the ATR algorithm attempts to match the target with a template, the operator is able to view the 3-D image, manipulating the display to view the target at different aspects. The ATR algorithm then sends a message to the operator's display that shows the target is a particular type of enemy tank, and provides data that shows how closely the target matches the template and the probability the template match is correct. The operator then follows the rules of engagement to pass this positive identification of the target to those who can use the information for targeting.

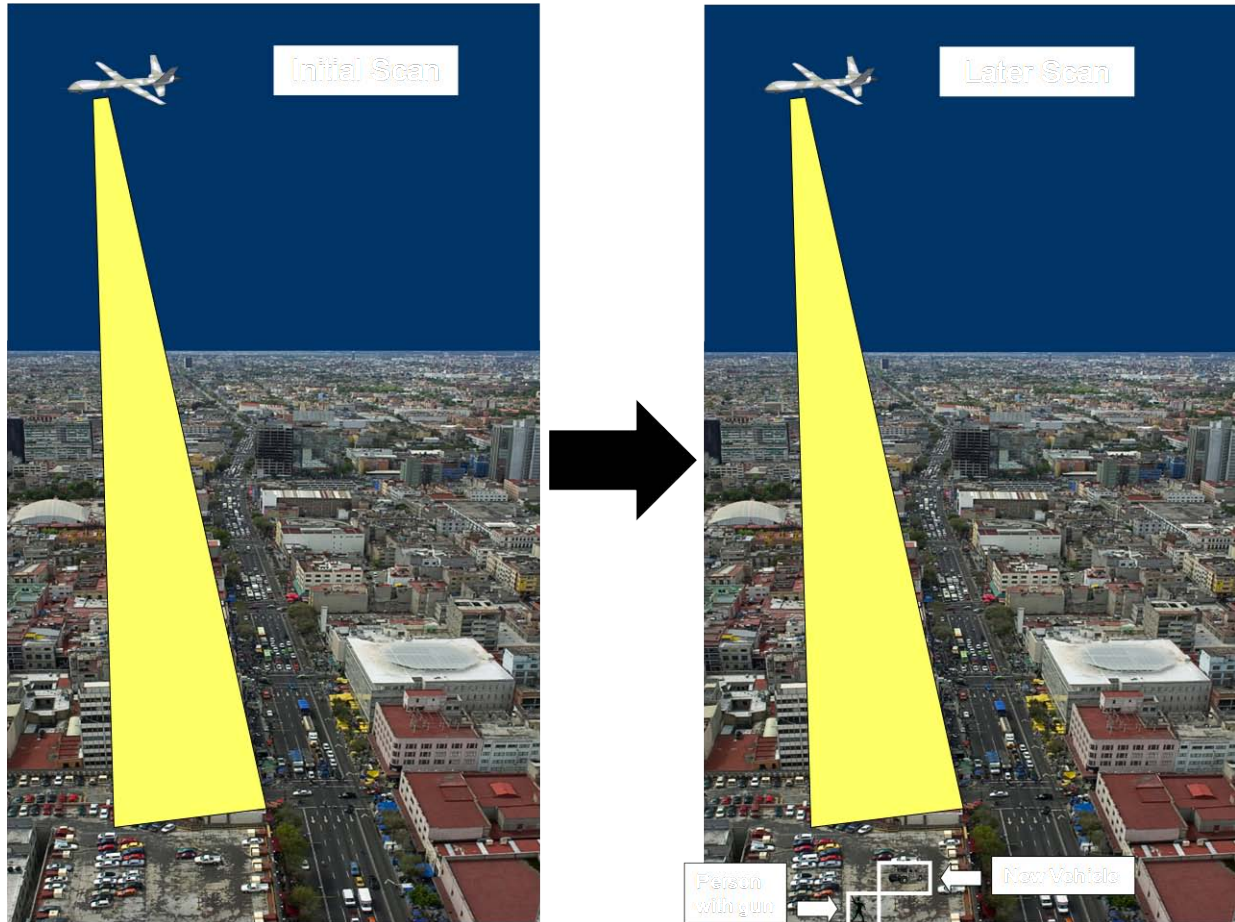**6.b. Vignette 2: Target Identification in an Urban Environment**

Figure 3 Vignette 2: Target Identification in an Urban Environment

The second vignette is that of targets in an urban environment, as illustrated in figure 3 above. In it, Army personnel are preparing to conduct night patrols of an urban area. Before the patrols begin, the LADAR platform images the area, collecting 3-D images at various aspect angles. These images are sent to the data processor and a high-resolution 3-D composite image of the area is produced. This high-resolution image is data-linked down to the Army patrol team and they study the image, manipulating it to look down each street and at different aspect angles. They use the image to plan their patrol and identify any areas of concern such as dead end or blocked streets, vehicles that are not normally in the area, and possible IED sites. The areas of concern are addressed and a plan is formulated to address these concerns. As the Army patrol

team heads out to the patrol, the LADAR platform continues to image the area. The LADAR

operator communicates with the Army patrol lead via chat and follows the location of the patrol

team using returns from the RF tags on the Army vehicles. As the patrol team proceeds, the

LADAR operator sends updated images of the area directly around the patrol team location.

These updated images are compared with earlier images to determine if anything has changed

and the patrol team makes decisions based on these changes and potential new dangers revealed

by the LADAR images.

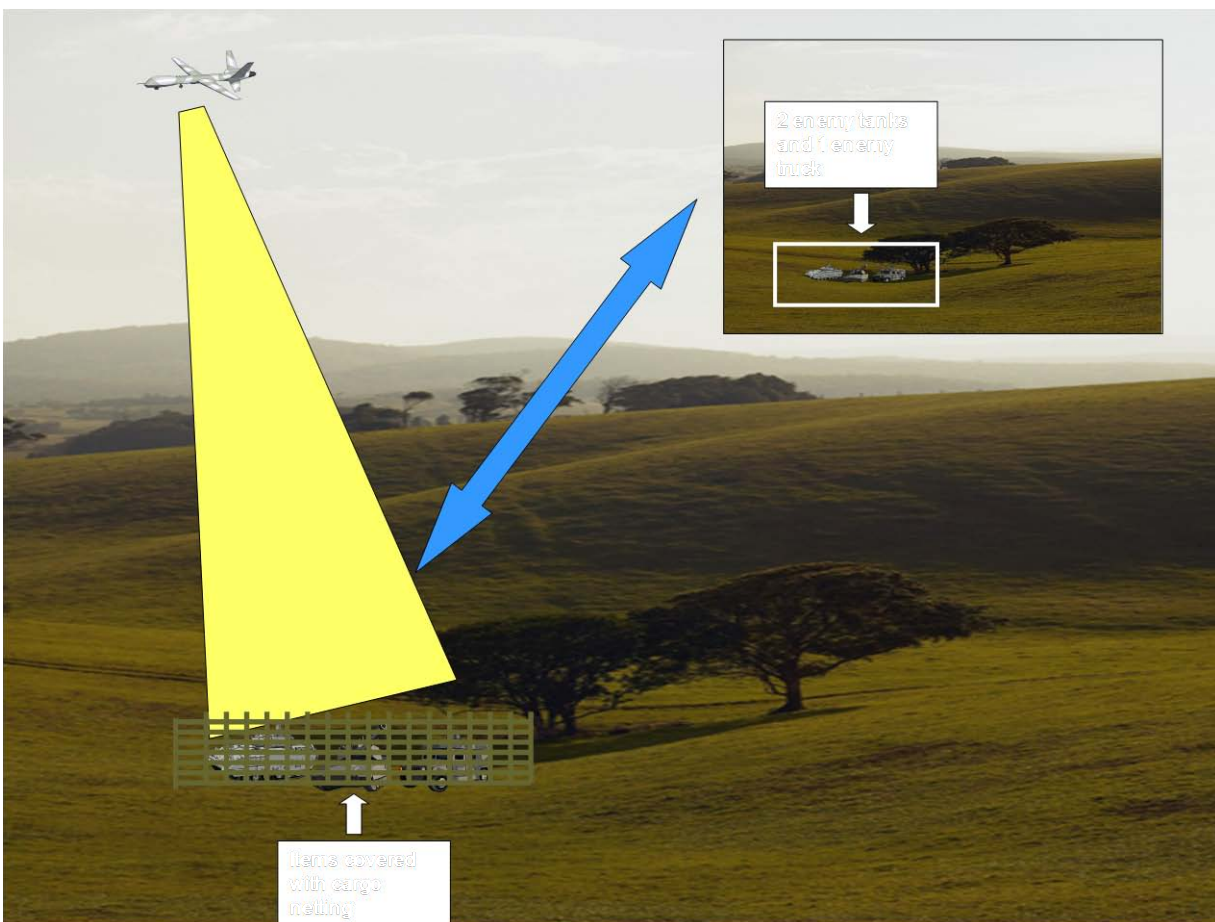### 6.c. Vignette 3: Identification of Camouflaged Targets

Figure 4 Vignette 3: Identification of Camouflaged Targets

The third vignette is that of identification of camouflaged targets, as illustrated in figure 4

above. In it, an area potentially containing enemy vehicles or equipment camouflaged with

cargo netting is reported by intelligence sources. The LADAR platform is tasked to image the area to determine what is underneath the netting. The LADAR platform images the area at different aspect angles and develops a high-resolution 3-D composite image of the area. The image is then sent through the ATR algorithm for identification of targets in the image. The image is also sent off-board to the AOC, where an imagery analyst inspects the image at various aspect angles. The ATR algorithm identifies the targets underneath the cargo netting and provides data that shows how closely each target matches the template and the probability that the template match is correct. The LADAR operator passes this information to the AOC. The ATR matching and information from the imagery analyst are used to positively identify the targets under the cargo netting as hostile vehicles. The target location and the 3-D image are passed to a bomber aircraft so that the crew can strike it.

7. Conclusions

ISR information has become critical in supporting warfighters in the battlespace. The United States has greatly increased the number of ISR platforms to meet this need, but the methods for target identification have not evolved to meet the type of enemy we are fighting today. The transition from conventional wars to more unconventional counter-insurgency operations makes it increasingly more difficult to target the enemy. Often, the enemy is inter-mixed among the civilian population, appearing for only a short time and then blending back into the populace. Target identification is not responsive enough to deal with this kind of enemy. In addition, urban environments and heavy foliage or camouflage make target identification extremely difficult.

High-resolution imagery that can operate in high clutter environments and automated target identification are needed to address these issues. LADAR is an emerging technology that

could potentially provide higher resolution, 3-D images. This, coupled with improvement in ATR algorithms, could allow for real-time identification of targets. LADAR offers advantages over traditional surveillance technologies such as SAR and EO/IR sensors because it provides higher-resolution images, can produce 3-D images, is all weather capable, and can detect obscured targets. The high resolution and ability to produce 3-D images that LADAR provides has the potential of supporting real-time target identification using ATR algorithms to match LADAR images with preloaded templates of potential targets.

The implications of this new technology for the military would be significant. Currently, real-time identification is almost non-existent in the battlespace. In addition, identification of obscured targets cannot be done through imagery surveillance. Identification of these types of targets requires other types of intelligence, such as a direct action team placing eyes on the target or longer-term intelligence approaches such as HUMINT. This method puts people in harm's way and risks letting the enemy know we are watching them. Real-time identification of obscured targets using LADAR with ATR would revolutionize the way we do battlespace surveillance. Development of these technologies would also provide opportunities in other areas. Some other items LADAR can be used for include battle damage assessment, identification of underground bunkers through vibrometry, IED detection, ground mapping, and chemical or biological agent detection and identification. LADAR also could be used for domestic security applications. Development of ATR will also allow for target identification with other sensors including SAR and EO/IR.

Real-time target identification of obscured targets is possible by the year 2035 with LADAR and ATR capabilities. These technologies have already been demonstrated and have shown great potential for improving military surveillance. The military should invest in

developing these technologies further, and integrating them together to solve the problem of real-time target identification.

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[3] Bromberg, Joan Lisa. "The Birth of the Laser", p. 26.

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[5] Ibid.

[6] DeKruger, David, Jesse Hodge, James C. Bezdek, James M. Keller, and Paul Gader. "Detecting Mobile Land Targets in LADAR Imagery with Fuzzy Algorithms", p. 197.

[7] Jelalian, Albert V., Laser Radar Systems, p. 1.

[8] Ibid, p. 1-2.

[9] Ibid, p. 152.

[10] Ibid, p. 151.

[11] Ibid, p. 151.

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[13] Ibid, p. 23.

[14] Ibid, p. 27.

[15] Wallace, A.M., R.C.W. Sung, G.S. Buller, R.D. Harkins, R.E. Warburton, and R.A. Lamb, "Detecting and Characterising Returns in a Pulsed LADAR System", p. 160.

[16] Ibid.

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[22] DeKruger, David, Jesse Hodge, James C. Bezdek, James M. Keller, and Paul Gader, "Detecting Mobile Land Targets in LADAR Imagery with Fuzzy Algorithms", p. 197.

[23] Ibid, p. 197.

[24] http://encyclopedia2.thefreedictionary.com/Bayesian+theory, p. 1.

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[26] Hauge, Robert, "LADAR Puts the Puzzle Together", p. 18.

[27] Ibid, 19.

[28] Ibid, 18.

[29] Chun, Cornell S.L., and Firooz A. Sadjadi, "Target Recognition Study Using Polarimetric Laser Radar", p. 274.

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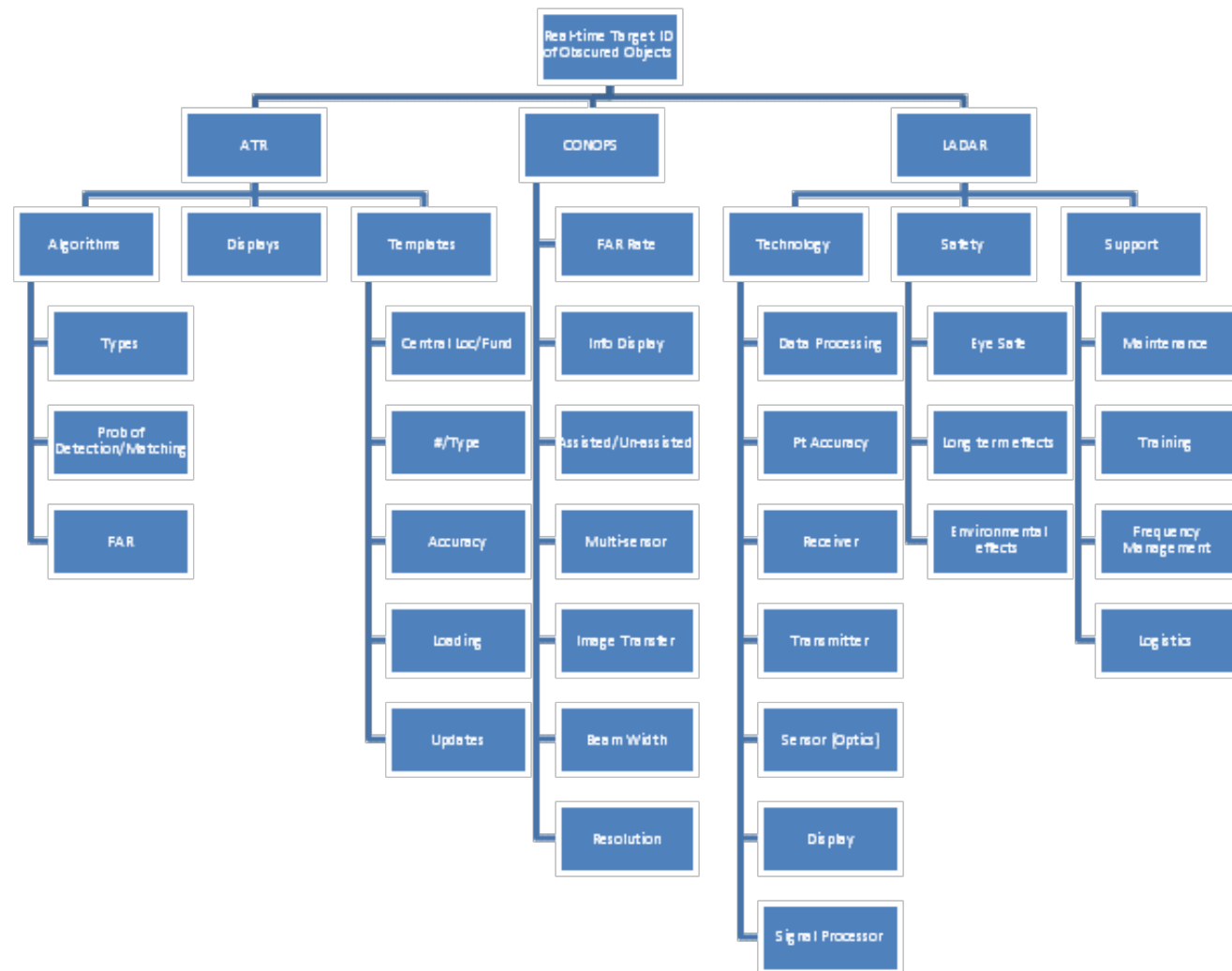
Appendix A – Research Methodologies

Several methodologies were used to conduct research for this paper. First, environmental scanning was used to determine current LADAR capabilities already demonstrated and research already done to advance LADAR imaging, processing techniques, and ATR algorithms. Sources from the literature review include background data on lasers and optical sensing. Additional sources specifically on LADAR include information on LADAR systems currently in development and testing, techniques for processing LADAR data to increase accuracy, methods for detecting targets partially obscured or in clutter, and methods for distinguishing between natural and man-made objects in LADAR images. Sources on target recognition include problems identified for ATR using LADAR images as well as some techniques being developed to overcome these issues. Finally, sources exist on emerging sensor technologies including LADAR and forecasts for when some of these technologies may be available in the future.

Next, using the information available from the environmental scan, a relevance tree was developed to determine the advances required to develop an operational capability for real-time identification of obscured targets using LADAR by 2035 (appendix B). The relevance tree considers LADAR, ATR, and Concept of Operations (CONOPS) as the three major factors in developing and operationalizing this capability. The relevance tree was used to help determine the future state of these factors necessary to support real-time target identification in an obscured environment.

Backcasting was used to compare the future state presented in the Relevance Tree with what is currently available to determine strategies needed to arrive at the future state. A notional timeline for when technologies need to be developed and made available is shown in appendix C.

Appendix B – Relevance Tree

Appendix C – Notional Timeline

| 2010 | 2015 | 2020 | 2025 | 2030 | 2035 |

LADAR

LADAR Development | LADAR Updates

★ Demo ★ Demo

ATR

ATR Development | ATR Updates

★ Demo ★ Demo ★ Demo

LADAR/ATR Integration onto Platform

Prototype | Integration | Testing

Ops Repr esentative Unit | Integration | Risk Red | DT/OT

★ OA

CONOPS

CONOPS Development | CONOPS Updates

★ CONOPS Approval ★ Fielding